Chapter 1 INTRODUCTION

This manual is to provide the bridge design engineers in the Office of Bridges and Structures (Bridge Office) of Georgia Department of Transportation (GDOT) with the guidance to design a typical bridge using GDOT's LRFD Mathcad ® programs.

1.1 DESIGN SPECIFICATIONS AND MANUALS

The design specifications used for these examples are the AASHTO LRFD Bridge Design Specifications, Eighth Edition, 2017 (LRFD Specifications). The articles of the specifications referenced to in this book are designated as LRFD x.x. For example, LRFD 3.1 refers to Article 3.1 of the LRFD Specifications.

The general design guidelines of GDOT included in the Bridge and Structure Design Manual (Design Manual) Revision 2.9 published on 5/26/2020 are followed in the examples. The references to the articles in the Design Manual are preceded by "DM". For instance, DM 3.1 refers to Article 3.1 of the Design Manual.

1.2 GDOT MATHCAD PROGRAMS

1.2.1 Development of GDOT Mathcad Programs

In many bridge design steps, it is imperative to use computer programs in certain parts, such as matrix calculations and iteration loops. Particularly, a multi-column pier design needs a frame analysis that includes high dimensional matrices and a prestressed concrete (PSC) beam design needs many iterative calculations to find the proper number of strands. For these reasons or simply for convenience, it is a common practice for the bridge designers to write their own programs or to use available existing ones.

Historically, GDOT has developed many in-house bridge design programs written in Fortran language. These programs have been widely used by GDOT bridge designers and consultants for many years. However, most of these programs are based on the AASHTO Standard Specifications for Highway Bridges, which are no longer used by the transportation community.

As part of the GDOT's LRFD design implementation efforts, a series of design and analysis programs have been developed by Dr. Y. Stanley Kim of LRFD Design Committee. These programs are developed for design of typical PSC girder bridges and they are written on Mathcad platform, intended to be easily understood and updated. The list of the design programs available for LRFD-based design and general-purpose calculations with brief descriptions is shown in Table 1.2.1-1.

Table 1.2.1-1 GDOT In-House Mathcad Programs

Name	Description
Barrier	GDOT Standard Barrier Design
Bearing BearingAnl	Steel-Reinforced Elastomeric Bearing Design/Analysis using Method A in LRFD Specifications
BentStiffness	Calculation of Stiffness of a Bent
Box Culvert	Design of GDOT Standard or Custom Box Culverts
DDimension	Calculation of "D" Dimension
HPBent	H-Pile Bent Design
MCPier	Multi-Column Concrete Pier Design
MSBent	Metal Shell Pile Bent Design
Overhang OverhangAnl	RC Slab Overhang Design/Analysis
PSBeam PSBeamAnl	PSC Beam (Simply Supported) Design
PSCBent	Prestressed Concrete Pile Bent Design
RCSlab RCSlabAnl	Reinforced Concrete (RC) Slab Design/Analysis
Seismic	Calculation of Seismic Loads and Longitudinal Tributary Length of Each Bent
SubLoad	Calculation of Loads on Substructure

1.2.2 Structure of Mathcad Programs

Each GDOT Mathcad program listed in the previous section consists of input, main body of calculation, and output. The main body is in the "collapsed" area in the default view, but it can be shown by double clicking the arrow indicating the area. In relatively long programs, such as MCPier and other substructure design programs, the main body is divided into a few sub-parts and hidden also in the collapsed areas.

The programs are written in double-paged sections. The left section is used for input/output and main calculations and the right section is used for notes, tables, and figures to help the users to understand the left counterpart. When the program is printed, the default is set to print only left section. The right section can be included in the print out by unchecking the "Print single page width" in the Mathcad menu File/Page Setup.

1.2.3 Update and Modifications

The name of the GDOT Mathcad programs in the Table 1.2-1 is followed by the LRFD Specification's version number and the date of program's revision in yyyy-mm-dd format. For example, MCPier_v8(2020-06-01) is the multi-column concrete pier design program following the AASHTO LRFD Specification 8th edition and it is updated on 06/01/2020.

The GDOT Mathcad programs will be updated periodically as needed by the GDOT LRFD Design Committee. The updates will be made typically when the LRFD Specifications and/or Design Manual are revised, the GDOT's design strategy is changed, and the errors and omissions are found. The update log that describes all historical update details will be kept in the bridge office server to be accessible.

All GDOT Mathcad programs are "open-source codes", so any users can modify or update on their own purposes. The only official programs located in the GDOT server will be maintained by the LRFD Design Committed.

1.3 DESIGN METHODOLOGY

1.3.1 Typical Design Sequence

A typical bridge design process using GDOT Mathcad programs consists of a sequential running of programs from RCSlab to one of the substructure design programs. Sometimes it is necessary to run multiple programs iteratively as well as to run the same program multiple times, changing input values. Figure 1.3-1 shows a typical design flow with the programs.

GDOT's design method assumes that the longitudinal loads applied on the bridge, such as braking force and wind load, are resisted by the multiple bents proportionally based on their stiffnesses. Therefore, a longitudinally stiffer bent will take more load than other more flexible bents. The stiffnesses of Individual bents are calculated in the BentStiffness program separately (one run per one bent) and the longitudinal tributary lengths of each bents are calculated in the Seismic program using the entire bridge (one run per bridge). The proportional load applied to the bent under design is calculated in the SubLoad program.

When running the GDOT programs, it is assumed that one bridge is between two expansion joints on slab. For a short bridge with no expansion joints on slab, the straightforward runs of programs following the design flow shown in Figure 1.3-1 will be enough. For a relatively long bridge that has one or more expansion joints on slab, the bridge will be divided into two or more "imaginary" bridges and some of the programs need to be run multiple times and the loads on the bents located under the expansion joints need to combine the individual loads calculated from the imaginary bridges before and after the bent. The detailed procedure is described in the following section.

When a bent consists of multiple piers, i.e. there are two or more separated pier caps, the individual piers need to be analyzed separately, as described in the section below.

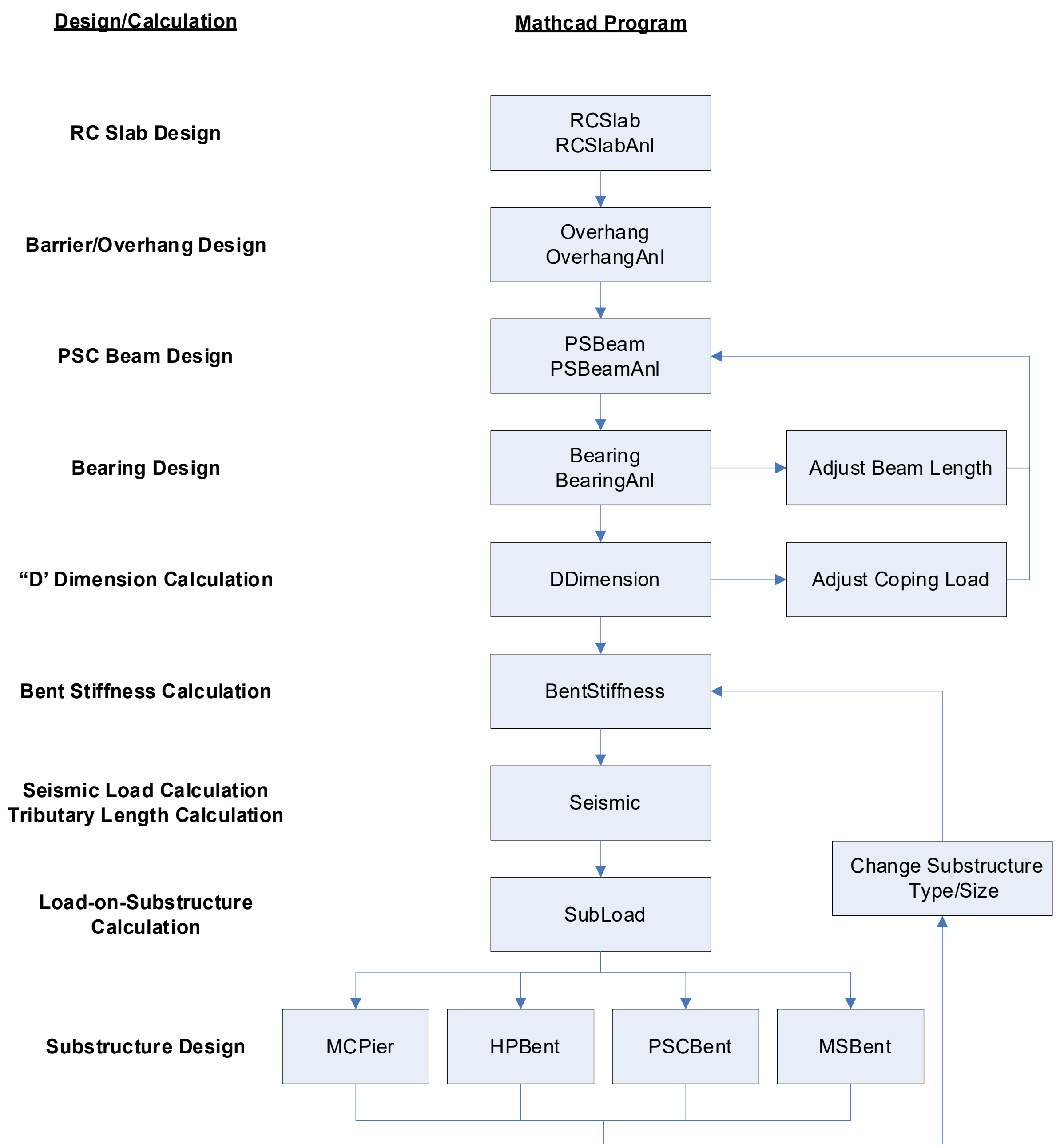

Figure 1.3.13-1 Design Flow Chart Using GDOT Mathcad Programs

1.3.2 Bridge with Expansion Joints on Slab

As described earlier, the bridges with the expansion joints on slab will be divided into multiple “imaginary” bridges that consist of spans between the joints. The following example sequence is for a bridge that consists of 5 spans and 6 bents, with one expansion joint on slab over bent 3.

1. Divide Bridge at Expansion Joints
   - The bridge #1 is from bent 1 to 3 and the bridge #2 is from bent 3 to 6.

2. BentStiffness Program
   - Run BentStiffness program twice for the bent 3 (under expansion joint). For the first run, the bent has bearings on back span only. For the second run, the bent has bearings on ahead span only. Use the whole substructure geometry (cap/column size and number of columns, etc) for both runs.
   - BentStiffness for other bents will have no changes.
   - Partial input for the first run for bent 3

$N_{bb} := 5$	No. of bearings in back span	$N_{ba} := 0$	No. of bearings in ahead span

   - input for the second run for bent 3

$N_{bb} := 0$	No. of bearings in back span	$N_{ba} := 5$	No. of bearings in ahead span

3. Seismic Program
   - Run Seismic program twice. First Seismic run is for the bridge #1 and will use the transverse/longitudinal stiffness of the bent 3 from the output of the first BentStiffness run and the second Seismic run is for bridge #2 and will use output of bent 3 of the second BentStiffness run.
   - First Seismic program run will use the span information (number of spans, span lengths, etc) that belongs to the bridge #1 and the second run will use the information from the bridge #2.
   - Partial input for the first run for bent 3

Span/Bent Data $ns := 2$ Number of spans (Data in the tables below will be read up to $(ns)^{th}$ span & $(ns+1)^{th}$ bent.

Span Lengths, Number of Elements, and Stiffnesses in Transverse Direction

Span Number	1	2										
Length (ft)	60	85										
# Elements	12	17										
EI (10^9 k-ft^2)	5.069	5.874										
EA (10^7 kips)	2.752	3.276										
W (kips)	619.603	809.487										

Note: W includes weight of superstructure and tributary substructure.

Stiffness (kip/in) of Bents in Girder Direction

Bent No.	1	2	3									
Transverse	98.533	551.295	279.888									
Longitudinal	27.89	119.246	73.243									

   - Partial input for the second run for bent 3

Span/Bent Data $ns := 3$ Number of spans (Data in the tables below will be read up to (ns)th span & (ns+1)th bent.

Span Lengths, Number of Elements, and Stiffnesses in Transverse Direction

Span Number	1	2	3									
Length (ft)	60	60	60									
# Elements	12	12	12									
EI (10^9 k-ft^2)	5.069	5.069	5.069									
EA (10^7 kips)	2.752	2.752	2.752									
W (kips)	604.763	548.207	580.509									

Note: W includes weight of superstructure and tributary substructure.

Stiffness (kip/in) of Bents **in Girder Direction**

Bent No.	1	2	3	4								
Transverse	165.269	92.518	35.561	98.533								
Longitudinal	31.431	27.398	20.734	27.89								

4. SubLoad Program
   - Run SubLoad program twice for the bent 3. First SubLoad run will use the longitudinal stiffness and seismic loads from the output of the first Seismic run and the second SubLoad run will use output of second Seismic run.
   - For other bents, use information of the bridge (bridge length and distance to fixity) that the bents belong to.
   - Partial input for the first run for bent 3

$L_{br} := 145 \cdot ft$ Bridge length (between exp. joints) $L_{tr} := 48.2 \cdot ft$ Longitudinal tributary length

$L_{sh} := 85 \cdot ft$ Distance to fixity (negative if this bent is behind the fixity)

$W_s := 43.25 \cdot ft$ Slab width in normal direction $W_r := 40 \cdot ft$ Roadway width in normal direction

$x_L := 1.625 \cdot ft$ Distance from left slab end to load $x_R := 1.625 \cdot ft$ Distance from right slab end to load

Note: Uniformly distributed wheel load in transverse direction can be placed at the barrier face.

$x_M := 21.625 \cdot ft$ Distance from left slab end to centerline

	Span Ln (ft)	No. of Beams	Distance (ft) between CL Beams **in Normal Direction** D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8	D_9	D_{10}	D_{11}	D_{12}
Back Span	85	5	4.125	8.75	8.75	8.75	8.75	0	0	0	0			
Ahead Span	0	0	4.125	8.75	8.75	8.75	8.75	0	0	0	0			

Note: Input all beams in the superstructure for a multi-pier bent.

   - Partial input for the first run for bent 3

$L_{br} := 180{\cdot}ft$ Bridge length (between exp. joints) $L_{tr} := 52.6{\cdot}ft$ Longitudinal tributary length

$L_{sh} := -60{\cdot}ft$ Distance to fixity (negative if this bent is behind the fixity)

$W_s := 43.25{\cdot}ft$ Slab width in normal direction $W_r := 40{\cdot}ft$ Roadway width in normal direction

$x_L := 1.625{\cdot}ft$ Distance from left slab end to load $x_R := 1.625{\cdot}ft$ Distance from right slab end to load

Note: Uniformly distributed wheel load in transverse direction can be placed at the barrier face.

$x_M := 21.625{\cdot}ft$ Distance from left slab end to centerline

	Span Ln (ft)	No. of Beams	Distance (ft) between CL Beams in Normal Direction D_1	D_2	D_3	D_4	D_5	D_6	D_7	D_8	D_9	D_{10}	D_{11}	D_{12}
Back Span	0	0	4.125	8.75	8.75	8.75	8.75	0	0	0	0			
Ahead Span	60	5	4.125	8.75	8.75	8.75	8.75	0	0	0	0			

Note: Input all beams in the superstructure for a multi-pier bent.

5. Combine the SubLoad outputs for input to Substructure Design Program (HPBent/MCPier/PSCBent/MSBent)
   - Use a spreadsheet to combine the loads for bent 3 as below.
   - Some SubLoad outputs from bridge #1 and #2 will be summed.
   - Some other SubLoad outputs are same for bridge #1 and bridge #2, and only one output will be used.
   - Horizontal Wind Loads (HW)

WS_{U_TR}	WS_{U_LN}	WS_{B_TR}	WS_{B_LN}	WL_{TR}	WL_{LN}
#1 + #2	#1 + #2	#1 or #2	#1 or #2	#1 + #2	#1 + #2

   - Vertical Wind Loads (VW1, VW2 & VW3)

Bm-1	Bm-2	Bm-3	Bm-4	Bm-5	…
#1 + #2	#1 + #2	#1 + #2	#1 + #2	#1 + #2	#1 + #2

   - Temperature/Shrinkage Loads (TU)

TU_{TR}	TU_{LN}	SH_{TR}	SH_{LN}
#1 + #2	#1 + #2	#1 + #2	#1 + #2

   - Miscellaneous Loads (MS)

BR_{TR}	BR_{LN}	CE_{TR}	CE_{LN}	WA_{U_TR}	WA_{U_LN}	WA_{B_TR}	WA_{B_LN}
#1 + #2	#1 + #2	#1 or #2	#1 or #2	#1 + #2	#1 + #2	#1 or #2	#1 or #2

   - Vertical Loads from Centrifugal Force (CE)

Bm-1	Bm-2	Bm-3	Bm-4	Bm-5	…
#1 or #2	#1 or #2	#1 or #2	#1 or #2	#1 or #2	#1 or #2

   - Earthquake Loads (EQ)

EQ_{TR}	EQ_{LN}	Bm-1	Bm-2	Bm-3	Bm-4	Bm-5	…
#1 + #2	#1 + #2	#1 + #2	#1 + #2	#1 + #2	#1 + #2	#1 + #2	#1 + #2

- Vehicular Collision Force (CT)

CE_{TR}	CE_{LN}
#1 or #2	#1 or #2

- Live Load Case (LL): Run SubLoad program with full back span and ahead span information. This will create Live Load Case output, different from output #1 or #2. Copy this output to the input for substructure design program.

6. Substructure Design Program (MCPier/HPBent/PSCBent/MSBent)
   - Run MCPier/HPBent/PSCBent/MSBent program as applicable. Use the load data combined as above.

1.3.3 Multi-Pier Bent

When a bent consists of multiple piers, each pier needs to be analyzed separately and the results will be combined to calculate the stiffness of the entire bent. The following sequence is for a bent with 2 piers. The left pier has one column and two beam lines, and the right pier has two columns and three beam lines.

1. BentStiffness Program
   - Run BentStiffness program for each pier at the bent separately.
   - Partial input for run for left pier

$nc := 1$	Number of columns	$S_C := 0 \cdot ft$	Column spacing
$L_{ohl} := 6.78125 \cdot ft$	Length of left overhang	$L_{ohr} := 8 \cdot ft + 6 \cdot in$	Length of right overhang
$N_{bb} := 2$	No. of bearings in back span	$N_{ba} := 2$	No. of bearings in ahead span

   - Partial input for run for right pier

$nc := 2$	Number of columns	$S_C := 13.875 \cdot ft$	Column spacing
$L_{ohl} := 4.5 \cdot ft$	Length of left overhang	$L_{ohr} := 4.5 \cdot ft$	Length of right overhang
$N_{bb} := 3$	No. of bearings in back span	$N_{ba} := 3$	No. of bearings in ahead span

2. Seismic Program
   - Run Seismic program just once for the entire bridge (between the expansion joints).
   - In the input data, the stiffness of the bent will be the sum of the stiffness of left and right piers at the bent in transverse and longitudinal directions, respectively.

3. SubLoad Program

- Run SubLoad program for each pier at the bent separately.
- In the first part of input data (geometry input), the superstructure information shall include all the beams at the bent, not just the beams on the pier under design.
- In the last part of input data, choose the multi-pier option and input the starting and ending beam numbers on the pier under design from back and ahead span, respectively.
- Input the ratio of stiffness of pier under design to the stiffness of entire bent, calculated from output of BentStiffness for transverse and longitudinal directions, respectively.
- Partial input for run for left bent

Multi-pier Bent	$mp := 1$	Mult-pier in this bent? (0=no, 1=yes)		
	$bb1 := 1$	Starting back span beam no. on pier (Ignore if mp=0)	$bb2 := 2$	Ending back span beam no. on pier (Ignore if mp=0)
	$ba1 := 1$	Starting ahead span beam no. on pier (Ignore if mp=0)	$ba2 := 2$	Ending ahead span beam no. on pier (Ignore if mp=0)
	$\lambda_T := 0.356$	Ratio of stiffness of pier under design to entire bent in transverse girder axis (Ignore if mp=0)		
	$\lambda_L := 0.395$	Ratio of stiffness of pier under design to entire bent in longitudinal girder axis (Ignore if mp=0)		

- Partial input for run for right bent

Multi-pier Bent	$mp := 1$	Mult-pier in this bent? (0=no, 1=yes)		
	$bb1 := 3$	Starting back span beam no. on pier (Ignore if mp=0)	$bb2 := 5$	Ending back span beam no. on pier (Ignore if mp=0)
	$ba1 := 3$	Starting ahead span beam no. on pier (Ignore if mp=0)	$ba2 := 5$	Ending ahead span beam no. on pier (Ignore if mp=0)
	$\lambda_T := 0.644$	Ratio of stiffness of pier under design to entire bent in transverse girder axis (Ignore if mp=0)		
	$\lambda_L := 0.605$	Ratio of stiffness of pier under design to entire bent in longitudinal girder axis (Ignore if mp=0)		

4. Substructure Design Program (HPBent/MCPier/PSCBent)
   - Run substructure design program for each pier at the bent separately.
   - Copy and paste the loads calculated from SubLoad program for pier under design.